LEDAPS: Mapping North American Disturbance from the Landsat Record

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***Abstract*—The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) project is creating a record of forest disturbance and regrowth for North America from the Landsat satellite record, in support of the carbon modeling activities. LEDAPS relies on the decadal Landsat GeoCover data set supplemented by dense image time series for selected locations. Imagery is first atmospherically corrected to surface reflectance, and then change detection algorithms are used to extract disturbance area, type, and frequency. Reuse of the MODIS Land processing system (MODAPS) architecture allows rapid throughput of over 1500 MSS, TM, and ETM+ scenes. Initial ("Beta") surface reflectance products are currently available for testing, and initial disturbance products will be available by the end of 2004.**

Keywords-component; carbon, ecosystems, Landsat, disturbance, remote sensing, atmospheric correction

I. INTRODUCTION

Given the importance of CO_2 and methane as greenhouse gases, it is natural that considerable research has been devoted to better constraining the global carbon budget. Although fossil fuel emissions have released some 120 Pg of carbon to the atmosphere, observed increases in atmospheric CO_2 can only account for about half of the anthropogenic emissions. The oceans can account for about half of this carbon sink, but some mechanism in the land biosphere appears to be absorbing a significant fraction of this anthropogenic carbon as well [1]. Numerous sink mechanisms have been postulated, including enhanced vegetation growth due to climate change and fertilization, suppression of fire, and regrowth of previously logged forests [2,3,4,5,6]. To date, none of these mechanisms have been conclusively ruled out, or conclusively proven.

Biogeochemical models offer a useful approach to simulating the response of ecosystems to environmental factors, to better constrain carbon cycling. One common difficulty, however, has been the lack of detailed information on disturbance regimes across large areas. Disturbance events themselves (e.g. fire, insect defoliation, harvesting) tend to release large amounts of carbon to the atmosphere, although the exact magnitude depends on the type and severity of disturbance. Conversely, during recovery from disturbance productivity increases relative to respiration, leading to a net ecosystem transfer from the atmosphere to the biosphere. Interannual variability in disturbance (fire) does account for a significant part of the interannual variability in atmospheric CO_2 levels globally [7]. In some cases (e.g. the southeastern U.S.), intensive harvests have led to a condition of "perpetual disturbance", and the long-term replacement of natural pine and mixed-deciduous forest with young planted pine could have significant regional effects on carbon sources and sinks. Although the age distribution of FIA inventory plots gives some information on historical disturbance, stand-age is not one of the better-constrained FIA attributes.

Fine-resolution satellite imagery from the Landsat program offers a way to monitor the history of disturbance at continental scales, but to date this record has not been analyzed systematically. A new project, the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) is now mining the 32-year Landsat archive to create wall-to-wall, decadal maps of forest disturbance across North America, in support of the upcoming North American Carbon Program (NACP) [8]. We use the NASA/EarthSatellite Corporation GeoCover data set to produce atmospherically corrected surface reflectance images, and then perform change detection to identify the location and type of disturbance events. By building on the existing MODAPS processing system used by MODIS, LEDAPS is able to automatically generate these products from some 1500 Landsat scenes in a few days of processing time. The project has recently released the first "Beta" version of the surface reflectance products, and will release initial disturbance maps from these products by the end of 2004. This paper describes the LEDAPS project in greater detail, and reports the current status of the mapping algorithms and product suite.

II. LEDAPS PROJECT OVERVIEW

Our overall objective is to produce maps of forest disturbance type, area, and frequency that can be used within biogeochemical models. To be useful to the carbon modeling community, these products must be coarsely gridded (e.g. 0.01 – 0.10 degree resolution), and aggregated to record the current probability of disturbance for any given grid cell. They must also record the probability of forest regrowth/recovery following disturbance. While coarse-resolution satellite data can be used to capture the history of large disturbance events (e.g. major fires), fine-resolution changes within forests often reflect human activities (logging, clearing, urbanization), and can only be observed accurately using <100 meter resolution data.

The LEDAPS project developed from a need for accurate maps of land-cover change and disturbance, articulated in a number of USGCRP planning documents and at workshops held as part of the NASA GSFC Carbon Cycle Initiative formulation activity in 2001. Of particular importance is the active role of the user community, including the carbon modeling community, in specifying, validating, and using the products. Reactions from the user community can then guide future reprocessing and product improvement. LEDAPS currently has participation from researchers within NASA, USDA, US Forest Service, Fluxnet Canada, the Canadian Forest Service, and the Canadian Centre for Remote Sensing.

The Landsat GeoCover dataset is the primary input to our disturbance mapping activity. GeoCover consists of global, cloud-free MSS, TM, and ETM+ coverages, centered on three epochs: 1975, 1990, and 2000. Where possible, images from the peak of the growing season were selected for inclusion. These data were then precision geolocated and orthorectified, to give a geodetic accuracy of better than 50 meters RMS. The GeoCover product was purchased from EarthSatellite Corporation through the NASA Science Data Purchase program, and can be obtained from USGS EROS Data Center or through the University of Maryland Global Land Cover Facility (GLCF).

Given the variability in atmospheric conditions across images, it was first decided to atmospherically correct each image. The procedure, described in detail below, is derived from the MODIS Land 6S radiative transfer approach [9]. Given the updated calibration coefficients recently published for Landsat-5 TM, it is possible to independently correct imagery from both 1990 and 2000. For older MSS data, neither the calibration nor the spectral coverage is adequate for an independent correction. Instead we will rely on image rectification techniques to normalize the ~1975 MSS radiometry to the 1990 TM data for the same location. The Hall et al. [10] radiometric rectification algorithm offers the best approach for this application, since the radiometric adjustment is only based on non-vegetated targets, and thus vegetation phenology is preserved through the adjustment.

Disturbance and regrowth will be mapped from the surface reflectance imagery. Currently, we envision two types of disturbance mapping algorithms. Initial products will be generated using radiometric change detection techniques to classify pixels as either disturbance (loss of biomass) or regrowth (recovery of biomass). For example, a Disturbance Index (tasseled cap Greenness – Brightness – Wetness) has recently been tested in the Pacific Northwest, Canada, and Russia with some success (S. Healy and W. Cohen, personal communication) (Fig. 1). The shape and size of disturbed patches will then be used to assess a likely disturbance type (e.g. fire, logging, other). One complication is that the GeoCover data are not all from the same season. Thus, a robust disturbance classifier needs to incorporate information on vegetation phenology, so that seasonal changes in reflectance are not confused with disturbance or regrowth. To this end, we are experimenting with using canopy reflectance models to calculated "expected" values of surface reflectance based on changes in solar geometry.

A second general approach to mapping disturbance is to avoid labeling pixels, instead extracting vegetation structural variables directly that pertain to carbon modeling. One

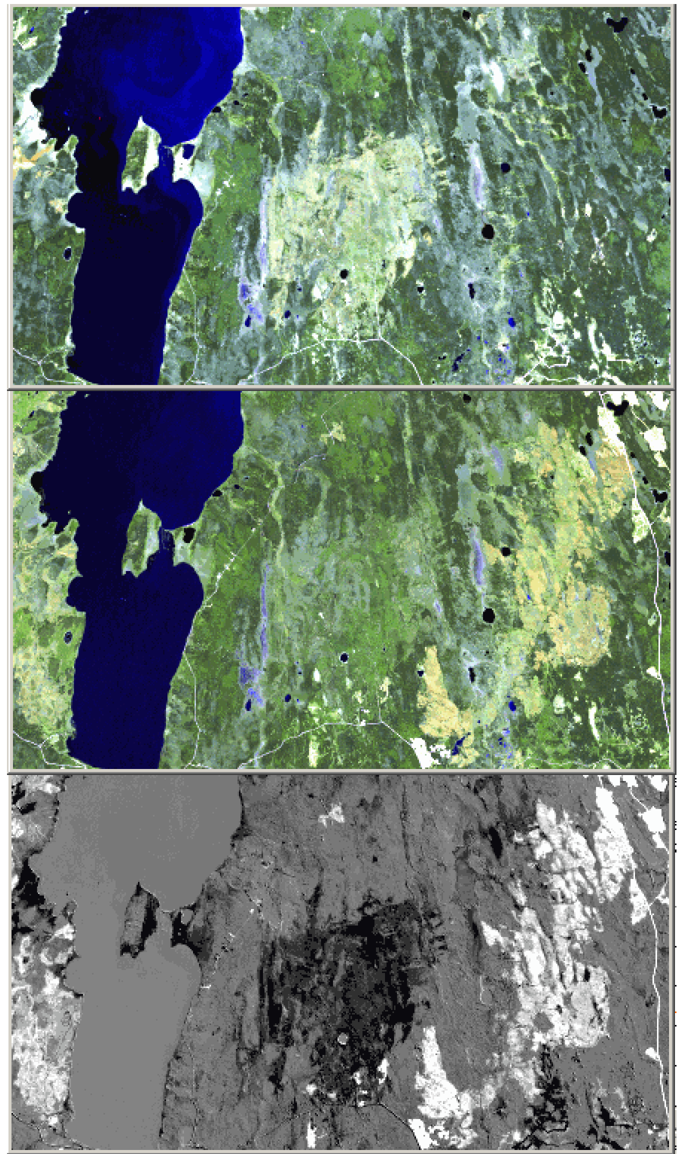

Figure 1. Example of disturbance mapping from Landsat TM/ETM+ data from Northern Canada (path 37, row22). Top: RGB (7-5-3) composite from August 1987; Center: RGB composite from August 2001; Bottom: Disturbance Index map showing new burn scars and logging (white), and young regrowth/recovery (black). Images are ~35 km across.

example is the "Multiple Forward Model" methodology [11]. In this approach, parameters are varied within a canopy reflectance model (e.g. canopy cover, stand height, LAI, stand composition, etc), and a lookup table of all possible reflectance values is generated. For pixels undergoing significant radiometric change the lookup table may be used to characterize the degree of structural change between two dates.

Both of these approaches will be prototyped within the LEDAPS processing system. Disturbance products will be produced that record the timing and type of disturbance, and the stage of regrowth. These products will be available in gridded formats (e.g. 0.1 – 0.01 degree resolution) to facilitate carbon modeling applications within the NACP.

III. Surface Reflectance Processing

Since initiation of the LEDAPS project in 2003, the majority of effort has gone into development of the surface reflectance (SR) processing strategy for the TM and ETM+ data. In general, the approach is to use the 6S radiative transfer model to retrieve surface reflectance values given calibrated top-of-atmosphere reflectance data.

As with the MODIS land products, aerosol optical thickness is extracted directly from Landsat imagery, using the known relationship between the mid-infrared (2.2 μm) and visible (0.45-0.65μm) bands for dark vegetated targets [9]. Initial attempts to apply the MODIS algorithm directly yielded unsatisfactory results when compared with either ground-based Aeronet or MODIS optical thickness observations. The major problem appeared to be related to light scattered from bright targets in adjacent pixels to dark, vegetated targets (adjacency effect). The small pixel size of Landsat compared to the atmospheric thickness makes the imagery particularly susceptible to adjacency effects. To mitigate this problem, the imagery was first sub-averaged to 1km resolution before the selection of dark objects for aerosol mapping. This change yielded improved results.

Additional required atmospheric parameters include water vapor, ozone, and barometric pressure. Water vapor and pressure are derived from NCEP re-analysis grids for the date of image acquisition. Ozone values are derived from the TOMS record.

Several approaches are being taken to validate LEDAPS surface reflectance products:

- image-based aerosol estimates are compared to aerosol optical thickness measurements from the AERONET (Aerosol Robotic Network) for specific targets;
- Landsat surface reflectance products are compared directly to simultaneous MODIS swath-based surface reflectance products;
- aircraft-based radiometer data are compared to contemporary Landsat surface reflectance products;
- the temporal stability of “invariant” targets are examined across multiple Landsat reflectance products.

The first two of these analyses have been carried out for a limited number of Beta Landsat reflectance products. In general, aerosol measurements from the image-based algorithm compare well with Aeronet data (Fig. 2), although adjacency effects still cause errors in bright, urbanized areas. Landsat surface reflectance values correspond closely with simultaneous MODIS reflectance data, with the exception of band 1 (0.45-0.42 microns).

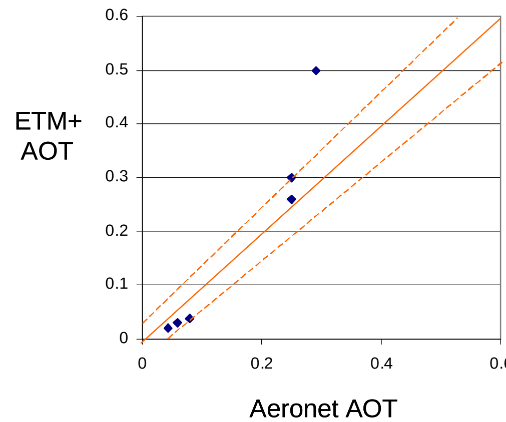

Figure 2. ETM+ Aerosol thickness values regressed against simultaneous AERONET AOT data for the blue band. Solid orange line is the one-to-one line, dashed lines represent AOT uncertainties of (0.05+0.2*AOT), the MODIS aerosol product uncertainty.

IV. Processing System Architecture and Scaling

LEDAPS reuses the MODIS Adaptive Processing System (MODAPS) to automate the processing of more than 1500 Landsat scenes to create co-registered radiometrically and atmospherically corrected products for North America. MODAPS is a modular system with components for ingesting ancillary products and instrument data, generating and archiving science products, and distributing these products to archive centers and science team members. Each day the MODAPS produces and distributes over 2TB of land, ocean and atmosphere products for the MODIS instruments on the EOS Terra and Aqua spacecraft [12]. These data are sent to Distributed Active Archive Centers (DAACs) for archiving and distribution to the public. An additional 300GB is shipped to scientists for quality assurance, product validation and for fusion with products from other missions over global study sites. MODAPS is also being tailored to meet the processing, archiving and distribution needs for the OMI (Ozone Monitoring Instrument), which will be launched on the EOS Aura spacecraft in 2004.

The modular architecture of the MODAPS, illustrated in Fig. 3, allows developers to easily tailor the system by replacing any sub-system, such as the Archiver, or sub-system component such as Legato Networker, with alternative software if desired. For the proposed effort subsystems that handle job execution and near-line archiving (Scheduler, Archiver and the Operations Interface) will require only minor customization. Sub-systems which acquire and store input data sets or ship data products will be tailored to meet the needs of the specific Landsat and GLAS data sets and interfaces to data providers. These sub-systems include: Ingest, which will be modified to ingest Landsat Level 1 Geocover data from the UMD Global Land Cover Facility and the web interface which will be talored for distribution of the LEDAPS products.

In MODAPS, data products are generated by Product Generation Executives (PGEs) which are launched and monitored by the Scheduler sub-system. The MODIS PGEs are programs written in C or Fortran which are combined with the EOS Science Data Processing Toolkit (SDP-TK), which includes HDF support and routines that isolate science software from operating system calls to promote portability, and Perl scripts, which handle data staging for production runs. Most of the development effort for this project will be concentrated in the area of creating PGEs for Landsat reflectance and disturbance products that will run on the commodity processors

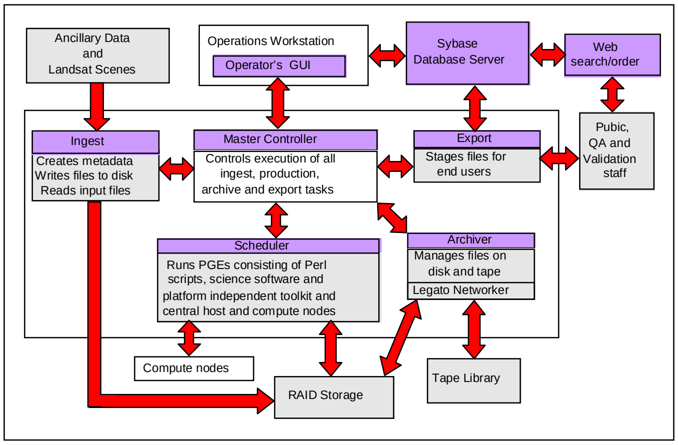

Figure 3. Schematic diagram of MODAPS architecture.

used by MODAPS. At this point, Landsat processing in MODAPS has produced a beta version of the land surface reflectance product.

The MODAPS hardware environment consists of a central production server, a set of low-cost compute nodes and a database server connected to a high-speed network. The central production server communicates with data providers and the data distribution sites through the Internet. Online disk storage used for distribution and the automated tape library used for storing products are connected to the central production server. Products are generated both on the central server and on compute nodes attached to the central server via Gigabit Ethernet. Each compute node is a two-processor system running Linux with sufficient memory and local storage to hold all input files, all output products and all PGEs required for processing. After processing products are copied to the central and stored in the central RAID storage and are written to the near-line tape library. A database server maintains an overall picture of the production system, including the location of the product files, status of the jobs, etc. For Landsat processing, the system has been sized to hold an on-line copy of the entire input data set (about 1TB) and two versions of the output products (about 2TB) and allow the North American data set to be processed within a month. The capacity to reprocess the data set several times each year and store two versions online will enable us to explore new algorithms from the community and evaluate the changes. In addition to the production system, an independent test system will be used to host one or more instances of MODAPS software that will be used for tailoring MODAPS and for algorithm development, testing, and quality assurance.

Beyond minimizing development costs and reducing risk, reusing the MODAPS system leverages a well-trained operations and sustaining engineering staff that is familiar with supporting production on the MODAPS system. We also share staff for software development, configuration management, integration, testing and quality assurance of products with the MODIS team. Similarly, the MODIS approach to algorithm development, integration and testing will be reused for Landsat processing. This approach is currently being used to integrate over seventy MODIS algorithms from science teams located at NASA's Goddard Space Flight Center and at universities throughout the world and has allowed the continual improvement in the quality of MODIS products.

V. PROJECT SCHEDULE AND PRODUCT AVAILABILITY

Initial (Beta) versions of LEDAPS surface reflectance products can be downloaded from the LEDAPS web site: http://ledaps.nascom.nasa.gov/ledaps/ledaps.html, which includes examples for selected areas (BOREAS study site, Pacific Northwest, Mid-Atlantic region, etc). Wall-to-wall coverage for all of North America will be released during Spring 2005. Disturbance products for the initial study regions will be released during Fall, 2004, with coverage for all of North America following within 12-18 months.

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